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640 Gb/s timing tolerant demultiplexing using a cascaded long-period fiber grating pulse shaper

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Abstract *An SMF inscribed with two polarization independent long-period gratings is used for sub-picosecond pulse shaping and validated in a 640 Gb/s data demultiplexing experiment, providing a jitter tolerance of 510 fs.*

Introduction

At high serial bit rates reaching several hundred Gigabits per second, timing jitter on data and clock signals becomes an important detrimental factor[1]. To increase the tolerance to timing jitter in ultra-fast optical switches, flat-top pulses have been demonstrated to be very beneficial[1].

In this paper, we utilize a single fiber device based on a delayed interferometer structure using two polarization-independent cascaded long-period gratings (LPGs) on the same 35 mm long piece of SMF. This pulse shaping device is demonstrated to create a 700 fs FWHM super-Gaussian pulse, which is the shortest ever reported. We present results on the demultiplexing of all 64 tributary channels.

Principle and experimental set-up

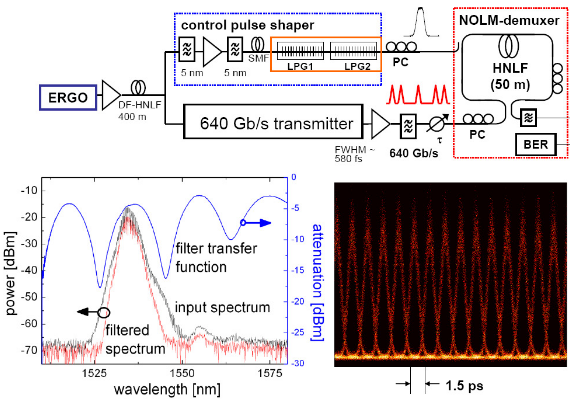

Fig. 1: Set-up for timing jitter tolerant demux (top), eye diagram of the 640 Gb/s OTDM signal (bottom right), transfer function and input/output spectra of the cascaded LPG pair (bottom left).

Fig. 1 shows the experimental set-up with the cascaded LPG pair used as pulse shaper, and an eye diagram of the 640 Gb/s OTDM signal obtained with an optical sampling oscilloscope. An Erbium Glass Oscillator (ERGO) pulse source runs at 10 GHz and emits 1.5 ps wide pulses at 1550 nm, which are used to create a super-continuum in 400 m of dispersion flattened highly non-linear fibre (DF-HNLF). The output from the DF-HNLF is used to generate the control and data signal by using two optical band-pass filters centered respectively at 1535 and 1557 nm.

When an optical pulse travels through the LPG, a coupling between the core and the cladding modes will occur, and the pulse will be split in two with a 3 dB ratio[2]. When the co-propagating pulses encounter a second LPG, the cladding mode pulse is coupled back in the core mode. The recombined pulses will interfere with each other giving rise to the fringe interference pattern[3] as seen in the transfer function in Fig. 1. The combined pulse intensity (after LPG2) will depend on the time delay between the cladding and core pulses, determined by the spacing between LPG1 and LPG2. This depends on the difference between the effective indices of core and cladding and on the spacing between the gratings[4]. In this experiment the pair of cascaded LPGs, inscribed in a conventional telecommunication SMF fiber[3], have a period of 381 μm and are spaced 35 mm apart. This leads to a time delay of 420 fs between the recombined cladding and core pulses.

Pulse characterization

Fig. 2 shows the simulated and experimental results with the used LPG-based delayed interferometer when a 350 fs gaussian pulse is sent through it.

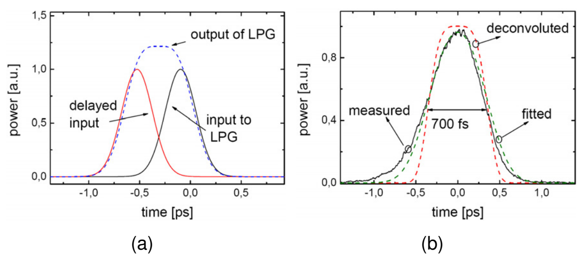

Fig. 2: LPG operation principle (left), measured cross-correlation trace of generated 700 fs flat-top pulse (right).

In the pulse shaper, the cladding mode part is delayed with 420 fs, resulting in a second order super-gaussian output pulse of 700 fs FWHM (Fig. 2, left). In Fig. 2, right, is seen the experimental result in terms of a cross-correlation trace when a 350 fs input pulse is used. Deconvoluting with the 450 fs sampling pulse yields a fit that agrees well with the expected simulated 700 fs FWHM super-gaussian pulse shape, confirming the operation of the pulse shaper. This 700 fs flat-top pulse is the shortest such pulse reported so far.

In order to validate this pulse shaper in a systems environment, the control pulses are adapted to a 640 Gb/s application by basically using more appropriate input pulse widths, here 1.1 ps.

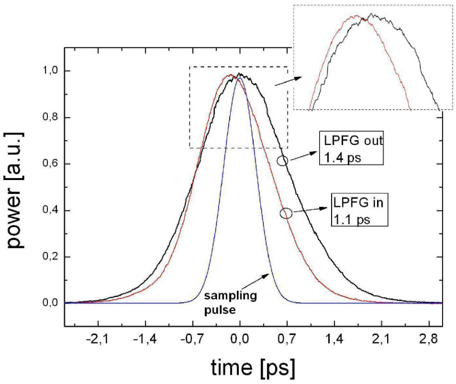

Fig. 3: Cross-correlation traces of the input and output of the LPGs.

Fig. 3 shows the cross-correlation traces of the input 1.1 ps pulse and the output of the pulse shaper 1.4 ps pulse with its rounder top intensity profile. This pulse is subsequently used as control in a nonlinear optical loop mirror (NOLM) with 50 m of HNLF (dispersion slope S$\sim$0.018 ps/(nm^{2}km), zero dispersion at λ_0=1551 nm, and non-linear coefficient $\gamma\sim$10.5 W^{-1}km^{-1}). The data to be demultiplexed is a 640 Gb/s serial signal (2^7-1 PRBS, single-polarization). The compression stage, for generation of adequate data pulses, is done in a 100 m long dispersion flattened DF-HNLF and by off-carrier filtering with a 9 nm filter and further propagation in the transmitter for generation of 580 fs wide pulses centered at 1557 nm. The data pulses are demultiplexed down to 10 Gb/s for subsequent bit error rate (BER) characterization.

Demultiplexing performance

The measurements were made using the best-performing channel number 13. Fig. 4 shows the BER curve, having a sensitivity equal to the 10 Gb/s back-to-back case. To characterize the system tolerance to the timing jitter, the data signal was gradually temporally detuned from the control pulses and hence also from the switching window. Fig. 5 shows the BER measurement for different detunings. The measurements are carried out at a receiver power of 1 dB above the receiver sensitivity to allow for some measurement margin. The switch is seen to maintain error-free (BER$\leq10^{-9}$) performance with a 510 fs tolerance to temporal displacement. The BER increases rapidly for larger data-control pulse detuning, which is mainly due to the presence of the neighboring channels and their timing jitter. Also shown in Fig. 5, are the results of demultiplexing all 64 channels, in terms of receiver sensitivities. It was clearly possible to resolve all 64 channels. As it can be noticed from Fig. 5 the measured receiver sensitivity is worse for the second half of the channels. This is supposed to be related to drifting in the demultiplexer, especially the polarization, which was optimized only at the very beginning of the measurement. However all channels were error free with less than 6 dB sensitivity difference between the best and worst performing channel.

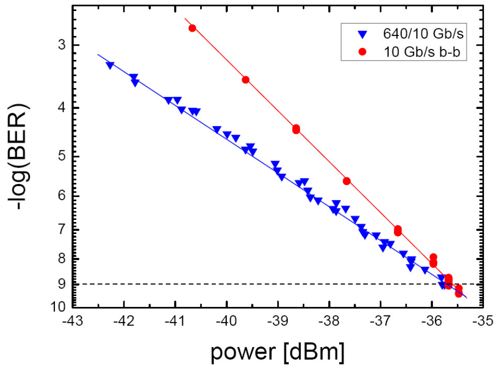

Fig. 4: BER characteristics for demultiplexing of a 640 Gb/s OTDM data signal into its 10 Gb/s tributary channels.

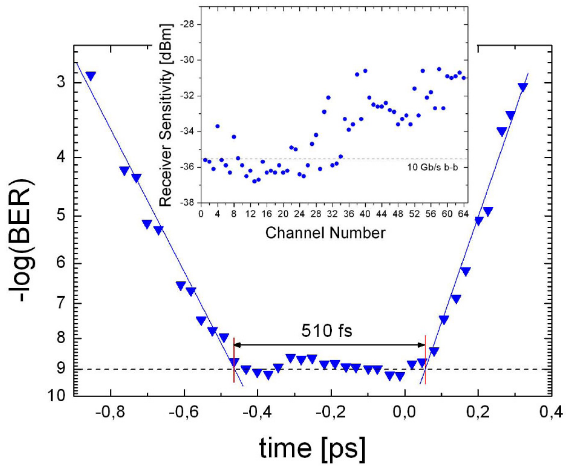

Fig. 5: BER at different control-data displacements (power=1dB over receiver sensitivity). Inset: receiver sensitivities for all 64 channels.

Conclusion

In this paper we reported on the utilization of a pair of LPG filters in a cascaded configuration for generation of control pulses used in timing jitter mitigation in OTDM data demultiplexing. The control pulses, were as narrow as 700 fs and had good performance in 640 Gb/s switching with a significant tolerance to timing jitter, and no power penalty for 640 to 10 Gb/s demultiplexing. We showed a 510 fs timing tolerance, and that all 64 OTDM channels were error-free.

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